IN THE UNITED STATES DISTRICT COURT
FOR THE SOUTHERN DISTRICT OF WEST VIRGINIA
CHARLESTON DIVISION

CIVIL ACTION NO. 2:11-cv-00087

MAYA NYE, et al., Plaintiffs,

v.

BAYER CROPSCIENCE, L.P., Defendant

Expert Report

By

Dr. M. Sam Mannan, PE, CSP

March 14, 2011

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A. INTRODUCTION

1 My Background

1.1 I have a BS, MS, and PhD in chemical engineering. I am a registered professional engineer in the states of Louisiana and Texas and I am a certified safety professional. I am a member of the American Institute of Chemical Engineers, American Society of Safety Engineers, the National Fire Protection Association, and the International Institute of Ammonia Refrigeration.

1.2 I am Regents Professor of Chemical Engineering and Director of the Mary Kay O'Connor Process Safety Center at Texas A&M University. I am the current holder of the T. Michael O'Connor Chair I in Chemical Engineering. I teach process safety both at the undergraduate and graduate level. My area of expertise within the chemical engineering discipline is process safety. I also teach continuing education courses on process safety and other specialty process safety courses in the United States and overseas. My research and practice is primarily in the area of process safety, incident analysis, and related subjects. I have attached a detailed résumé in Appendix A. As illustrated in my résumé, my career has spanned both industrial and academic experiences.

1.3 In this matter, pursuant to Federal Rule of Evidence 706, the Honorable Joseph R. Goodwin appointed me to serve as a court-appointed expert.

2 Matters Considered In Preparing this Report

2.1 As part of my work, I have considered the following information and conducted the following activities:

(1) Reviewed documents relevant to my analysis listed in Appendix C.

(2) Visited the Bayer CropScience site February 28, 2011 – March 2, 2011 and March 10, 2011, to conduct inspections, conduct interviews, and gather necessary information/data. The schedule for the two visits is given in Appendix D. Pictures taken during the visit are also included in

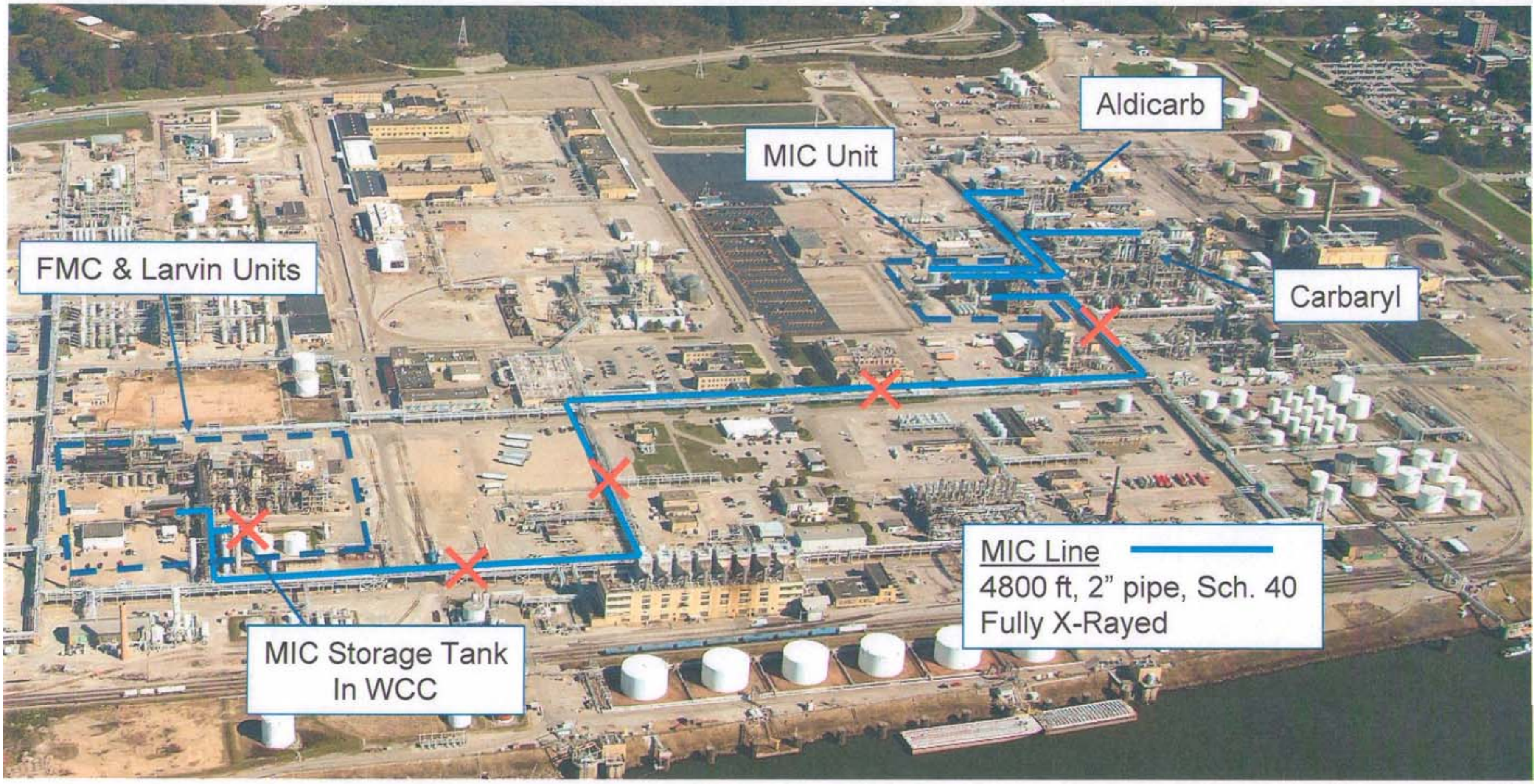
Appendix E.

(3) Conducted calculations for probabilistic risk assessment.

2.2 The Institute, West Virginia site, is a multi-employer site with operations owned and operated by Adisseo, Bayer CropScience, FMC, Catalyst Refiners Inc., Dow, Praxair, and Reagent Chemical.

2.3 I have limited the discussion of the chemical process to the Bayer CropScience methyl isocyanate operations. Figure 1 shows the extent of the MIC operations at the Institute Bayer CropScience facility at the time of the August 2008 incident. Figure 2 shows the extent of the modified MIC operations that is the subject of this matter. The process description for the modified operations is given later in this report.

Reduced MIC Activity – Transfer Line & WCC Storage Removal

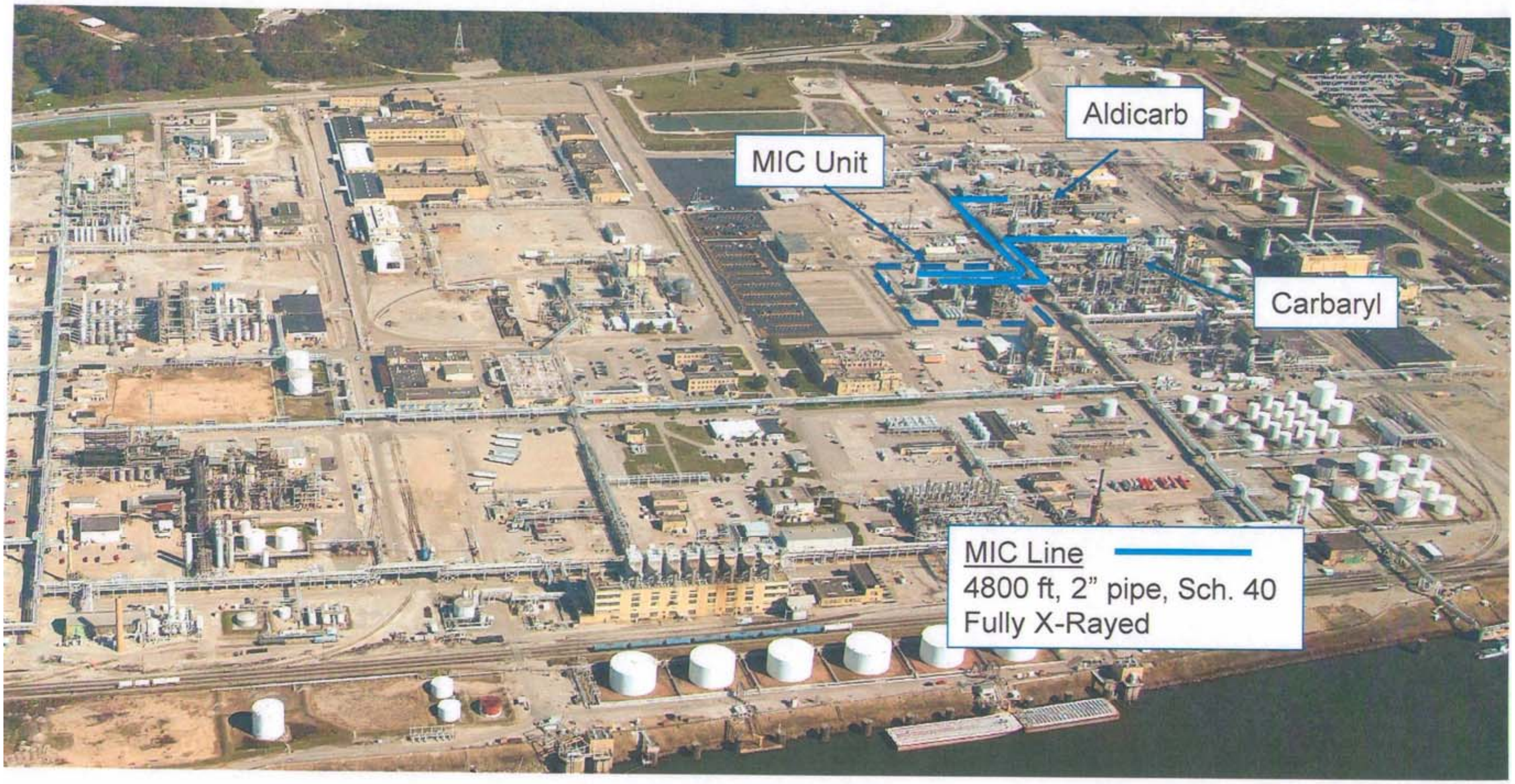


Presentation • March 1, 2011 • Slide 2

Bayer CropScience

Figure 1: Extent of MIC Operations at the Bayer CropScience, Institute, West Virginia Facility on August 2008

Reduced MIC Activity – Transfer Line & WCC Storage Removal



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Bayer CropScience

Figure 2: Extent of Modified MIC Operations at the Bayer CropScience, Institute, West Virginia Facility, March 2011

3 Court Order

3.1 My instructions are contained in a court order dated February 23, 2011 (Appendix B). The following is extracted from the order:

> *Dr. Mannan shall, before* ***March 14, 2011****:*
>
> *1. Physically inspect those portions of the Bayer CropScience (Bayer) facility in Institute, West Virginia that he deems relevant to this matter;*
>
> *2. Physically inspect the documents and electronically stored information that he deems relevant to this matter; and*
>
> *3. Perform any other necessary inspection or investigation he deems necessary to:*
>
> *A. Assess the process safety of the manufacture, storage, and transport of methyl isocyanate (MIC) unit at the Bayer facility; and*
>
> *B. Assess the probabilistic risk of a catastrophic incident involving MIC at the Bayer facility.*
>
> *By* ***March 14, 2011****, Dr. Mannan shall make available to the court and the parties a full written report of the results of his investigation. This report should contain the foundation for the expert's findings, and an assessment of (1) the process safety of the manufacture, storage, and transport of MIC at the Bayer facility, and (2) the probabilistic risk of a catastrophic incident involving MIC at the Bayer facility.*

3.2 I also have been ordered to make myself available the week of March 14, 2011 to testify at one or more depositions in Charleston, West Virginia. At the depositions, any party may inquire as to any contact or conversation I had with employees of the defendant corporation or with the plaintiffs and may also examine me about the documents I have reviewed in the course of his investigation. I also have been ordered to make myself available to testify at a public hearing on this matter in Charleston, West Virginia, beginning on **March 21, 2011**.

4 Modified Methyl Isocyanate Process Overview

4.1 A process flow diagram for the modified methyl isocyanate process is shown in Figure 3. Superheated phosgene (270°C, 56 psig) and MMA vapor (34°C, 60 psig) are both supplied from storage through vaporizers to a tubular reactor that produces MIC. MIC is produced in a two-step process: monomethylamine (MMA) and phosgene are reacted to create methyl carbamoyl chloride (MCC) and then, hydrogen chloride and MCC are thermally decomposed to produce MIC and HCl. Both of

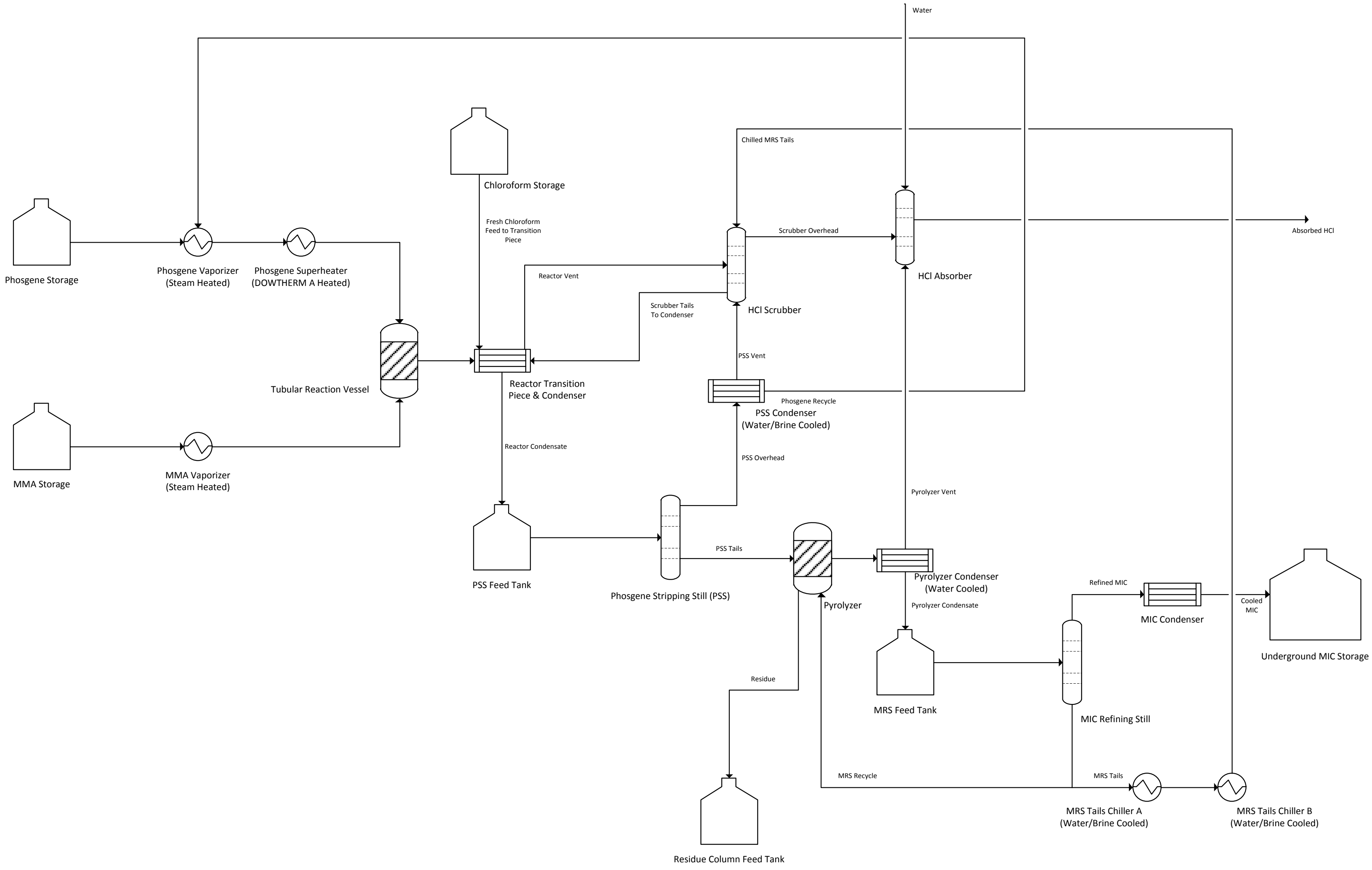

Figure 3: Modified MIC Process Flow Diagram

these steps occur in the same reactor, and no catalyst or further heating is necessary because of the fast kinetics and exothermic nature of the reaction. The exit temperature from the reactor is between 350-450°C. The reaction is allowed to run hot to prevent the condensation of monomethylamine hydrochloride, a solid with a melting point of 225°C.

4.2 The vapor product, fed to a transition piece, is cooled by the addition of chloroform spray on the product. This product then enters a condenser that is cooled by the addition of cold tails from the HCl scrubber. Most of the heavy ends (MIC, chloroform, phosgene, MCC from the reverse reaction) of the product condense and are sent to the phosgene stripping still (PSS) holding tank, while the light end (HCl) stays in the vapor phase and is vented to an HCl scrubber. The PSS is designed to strip phosgene out as a vapor while allowing the other components to condense and be sent to the pyrolyzer unit as PSS tails. The stripped phosgene is allowed to partially condense, with the leftover vapor going to the HCl scrubber and the condensate recycled back to the phosgene vaporizer to start the process over.

4.3 The pyrolyzer takes the PSS tails and decomposes the leftover MCC into MIC. The condenser to this reactor is designed at a sloping angle so that the condensed MIC doesn't contact the vaporized HCl, which would cause the reverse reaction to MCC. The HCl is not condensed and is sent as vapor to the HCl absorber, not to be confused with the HCl scrubber, which will be explained in the next section. The condensate from the pyrolyzer consists of MIC, MCC, and chloroform, and is sent to the MIC refining still (MRS) storage tank for use in the MRS. The purpose of the MRS is to vaporize the MIC to purify it while leaving the MCC and chloroform condensed. The purified MIC is sent to storage, while the MCC, chloroform, and trace amounts of MIC are split between being sent back to the pyrolyzer and being chilled and sent to the HCl scrubber.

4.4 The HCl scrubber is an apparatus that takes streams from the reactor condenser, the PSS condenser, and the MRS tails and separates HCl from the other components it is mixed with. The HCl is vaporized while the other components (phosgene, MCC, chloroform, trace MIC) are condensed and sent back to the reactor condenser as coolant (the

condensate is cooled from the chilled MRS tails). The vaporized HCl is sent to an HCl absorber along with the HCl from the pyrolyzer vent, where it is absorbed, in water.

4.5 Carbon dioxide (CO_2) buildup is a byproduct of water entering the MIC process. It occurs when water reacts with phosgene, MIC, or MCC. CO_2 analyzers are used to detect two specific cases: the case where CO_2 rapidly increases very suddenly, and the case where it slowly builds up over time. The purpose of the analyzers is to detect leaks at an early stage in the process to be able to take remedial measures for correcting raised CO_2 levels. Water contamination in the MRS product stream is monitored by a near-infrared spectrophotometer.

4.6 If the ratio of MMA to phosgene feed is allowed to drop too low (below 0.25) and the temperature drops too low (below 225°C), the undesired reaction to form monomethylamine hydrochloride begins to dominate, and the MMA and phosgene vapor feed piping may begin to plug and the MMA/phosgene reaction may back up into the head of the reactor. To prevent this, a control system has been developed to keep unreacted MMA from mixing with HCl produced by the MMA/phosgene reaction. Instrumentation monitors the temperature and pressure differentials around the reactor.

4.7 MIC operations are now limited to the MIC quadrangle (see Figure 2) containing the MIC manufacturing unit, MIC underground storage, and piping to adjoining aldicarb and carbaryl units. The maximum amount of MIC that can be stored onsite is 50,000 pounds in the underground storage tanks. There is no transportation of MIC inside or outside the plant except the piping within the MIC quadrangle discussed above.

5 Contents of this Report

In addition to this introductory section, this report contains four additional sections. Section B deals with the August 2008 incident and its aftermath. It is important to understand the August 2008 incident in order to ensure if root causes identified for the August 2008 have been addressed. Section C deals with the process safety management program at the Bayer CropScience facility. Section D deals with the probabilistic risk of

a catastrophic incident involving MIC at the Bayer CropScience facility. Section E provides my recommendations for improvements including improvements in safety systems and improvements in management and management systems. Finally Section F sets out my obligations as expert witness to the court.

B. THE AUGUST 2008 INCIDENT

6 Incident Description

6.1 The August 2008 incident did not occur in the MIC unit or any equipment or procedures associated with the MIC unit. The incident occurred in the methomyl unit. However, as described earlier, a review of the incident and remedial actions undertaken by Bayer is necessary to understand the status of process safety in the plant and risk of catastrophic incidents.

6.2 On August 28, 2008 at about 10:35 PM, a runaway chemical reaction occurred inside a 4,500 gallon pressure vessel, known as a Residue Treater, causing the vessel to explode in the methomyl unit at the Bayer CropScience plant in Institute, West Virginia. The incident occurred during a restart of the unit after an extended outage to upgrade the control system and replace the original, 29 year-old, corroded Residue Treater vessel with a new, stainless steel vessel. Two Bayer employees died in the incident and six volunteer firefighters were treated for possible toxic chemical exposure.

6.3 Since the incident, the Methomyl Unit has been shut down and decommissioned, and methomyl is now imported into the plant in dried powder form. In addition, methyl isocyanate, has been removed from the West side of the plant, where the Methomyl Unit was located, greatly reducing MIC inventory (Figure 1 shows the extent of MIC operations at the time of the incident and Figure 2 shows the extent of the MIC operations in the modified process). MIC is now confined to the East side of the plant, where it is made and used to feed to processes to make aldicarb and carbaryl. All three processes (MIC, aldicarb, and carbaryl) are currently adjacent to each other, eliminating long plant pipelines containing MIC. MIC is scheduled to be phased out completely by 2012.

7 Incident Investigation

7.1 Both Bayer and the Chemical Safety and Hazard Investigation Board (CSB) investigated the incident. They both concluded a runaway chemical reaction in the Residue Treater

caused the loss of containment. The runaway reaction resulted from:

- Deviation from the written startup procedures including bypassing critical safety devices intended to prevent such a condition
- Inadequate pre-startup safety review
- Inadequate operator training on the new Siemens Distributed Control System (DCS)
- Malfunctioning or missing equipment
- Bypassed critical safety devices
- Insufficient technical expertise in the control room during the restart

7.2 The CSB also concluded there was poor communications during the emergency between the Bayer and local emergency response agencies. The CSB also reported non-functioning air monitors at the site, and that no reliable data or methods were available to determine what chemicals were released or predict exposure concentrations.

8 The CSB Investigation Identified the Following Incident Causes

8.1 Failure to apply standard pre-startup safety review procedures and turnover practices to the methomyl control system redesign project. The equipment was not tested and calibrated before the unit was restarted.

8.2 Operations personnel were inadequately trained to operate the new distributed control system.

8.3 Malfunctioning equipment and inadequate DCS check out prevented the operators from achieving correct operating conditions in the crystallizers and solvent recovery equipment.

8.4 The out of specification methomyl solvent mixture was fed to the residue treater before it was prefilled with solvent and heated to the minimum safe operating temperature.

8.5 The incoming out-of-specification high concentration methomyl stream generated an exothermic, runaway reaction that overwhelmed the system and over-pressurized and catastrophically failed the reactor.

9 The Methomyl Process

9.1 The methomyl process began by reacting aldoxime and chlorine to make chloroacetylalodoxime. The chloracetylaldoxime reacted with sodium methyl mercaptide in methyl isobutyl ketone (MIBK) solvent to produce methylthioacetylaldoxime (MSAO). MSAO was reacted with methyl isocyanate (MIC) in MIBK to produce methomyl. Excess MIC was removed from the methomyl-solvent solution, then the solution was pumped to crystallizers where a de-solvating hexane was added to crystallize out the methomyl. The methomyl crystals were then removed via centrifuges as a cake, dried, and packaged as product. The liquid exiting the centrifuges, normally containing <0.5% MIBK, hexane, small quantities of methomyl and other trace impurities, was then sent on for treatment. The solvent was separated and recycled in a solvent recovery flasher. Bottoms produced from the flasher, including up to about 22% methomyl, was treated in a residue treater, which used dilution with MIBK, heat, and temperature control via cooling and solvent evaporation to destroy the methomyl in the residue to below 0.5%. The cleaned bottoms stream was then sent to the facility steam boilers as fuel.

9.2 Changes to the process during the outage, just prior to the explosion included a control system upgrade to a Siemens Distributed Control System and treater replacement. In 2007, prior to the DCS upgrade in the Methomyl unit, the Larvin unit, associated with the methomyl unit, had been upgraded to a similar Siemens DCS system. Bayer, assisted by Siemens, had trained the operators in the Larvin unit.

9.3 The Residue Treater had a maximum operating pressure of 50 psig. The Residue Treater pressure relief system was designed to protect from fire for a methomyl concentration not to exceed 1.0%.

9.4 The treater process included a vent condenser with piping on the top that was historically prone to blockages caused by trace amounts of salts solidifying in the vent. This would cause pressure rises, which would be corrected by steam treatment of the vent by the operators to re-melt the deposits.

9.5 The Residue Treater was operated by first pre-filling the treater with MIBK solvent to about 50%, then heating the solvent to 135^oC. The residue treater bottoms would then be gradually fed to the residue treater. It was supposed to be automatically fed. However, pluggage of the feed line, due to low flow rates during automatic feeding, resulted in a manual level control and feed by the operator. These changes in the operation were not recorded in the procedures. Also, there were programmed changes to the cooling logic, discovered during the incident review, that were not requested by the Unit and were not documented. Thus, operations personnel were unaware of the changes.

10 Deviations That Contributed to the Incident

10.1 The Standard Operating Procedure (SOP) required that the temperature of the material in the residue treater to be less than 130^oC, and a sample to confirm the composition must be taken. Also, the SOP required that a daily sample was supposed to be taken at 0700 hrs of the residue treater to confirm the composition. Neither sample was taken, because the dayshift operator was not aware the Residue Treater was being filled. This was because at shift-handover, the discussion was interrupted when the previous shift operator was assisting trouble-shooting a problem with a pump problem in the Larvin Unit, and the filling of the treater had not been noted in the electronic shift log.

10.2 Samples had been taken of the Mother liquor flasher feed stream that indicated a higher than normal methomyl concentration in the unit, up to 4% vs the normal less than 0.5%. However, in the process of troubleshooting the unit the operators forgot about the samples and did not check them. This would have indicated abnormally high concentrations of methomyl in the flasher, rather than abnormally low concentrations as was believed to be the case by the operators.

10.3 Sometime during the long outage to install the new DCS, a safety interlock, which prevented the flasher bottoms from being fed when the solvent treater was below 80^oC, or a maximum pressure bypass (according to CSB) had been by-passed and left in that mode. Also, an operational interlock, which prevented the feed control valve to the

treater from being opened until recirculation had been established, had been bypassed by the operators via the supervisor leaving the operational bypass screen (password protected), open. According to CSB, there was no place in the design or SOP to sample the flasher bottoms (feed to the treater). The designers believed sampling of the flash feed was sufficient as a control. Thus, a safety critical parameter, the concentration of the flasher bottoms/feed to the treater could not be confirmed prior to feeding the treater.

10.4 The new methomyl control system upgrades required revision to the SOP to incorporate changes to the DCS. The SOP was supposed to be upgraded and added as an electronic form. However, this was not done. Instead, a manual SOP was being used that was labeled, 'Draft I review 11/13/07." The displays on the DCS were in units different than the operators were used to, as they had been changed in the DCS upgrade. Hand-written notes had been placed by the board to convert to the new units by the operators, but they were incomplete. This confused the operators in the unit operation and contributed to the problems in controlling the solvent recovery system. Nevertheless, the PSSR indicated the DCS was checked out and okay to operate, and verbal approval to startup had been given by the supervisor.

10.5 The normal startup procedures require a solvent flush to the system including the residue treater; however, the day of the incident the flow restrictions upstream impeded completion of this recalibration because proper adjustments could not be made of the flow rate. Thus, the required solvent flush to the treater had never been performed. In addition, the SOP required the treater to be prefilled with solvent. This pre-fill was not performed. According to the Bayer investigation, it was due to the belief by some operators that the feed had no methomyl in it, as they were under the mistaken belief that methomyl had not formed due to the lack of crystal formation, and a "thin" feel to the fluid when fed out of the methomyl reactor.

10.6 Several pieces of equipment had malfunctioned during the startup. A valve to control the flow-rate for an instrument flush, reducing flow to a drip, had not been installed. Thus, a higher-than-normal flow of MIBK was fed to the upstream unit. In addition, according to the CSB, a broken stem to a water cooling valve had reduced cooling in the vapor

condenser.

10.7 The primary reason for the failure was a high level of methomyl in the flasher feed and bottoms. This was caused by control system problems in the solvent recovery unit and incorrect set points. Specifically the hexane feed control ratio was not correct, so the recovered hexane contained about 40% hexane, rather than the required less than 4%. This prevented the hexane from precipitating out the methomyl, which stayed in the solution and did not appear in the centrifuges downstream of the crystallizer. Also, the unit was manually feeding the crystallizer at a high rate, as the operators were observing little build up of cake in the crystallizer. In addition, the operators at the end of the unit towards the treater indicated the way pumps were operating, the material was less viscous than normal ("thin"), indicating (incorrectly) to them the material was solvent only. The potential significance of the lack of crystals in the centrifuges failed to capture the attention of the operators. According to the Bayer report, high concentration of MSAO losses in the flasher tails was due to MSAO losses in the MSS tails, caused because there was insufficient MIC in excess of the reaction step. The low MIC resulted from the variable MIC conditions being experienced in the MSS overhead due to a reactor side-draw condenser malfunctioning because of river water restrictions. The flow restrictions were caused by a plugged return header, a broken control valve stem, and the temporary use of hoses to supply the shell side of the condenser with water. Also the Bayer report states the operators stated to the investigators that sometimes they did not pre-feed the treater with solvent prior to operation. This was an occasional, previous practice they were familiar with that was prohibited in the SOP. The end result, according to a material balance estimate in the Bayer report, was a residual heater concentration of 40% methomyl and 20% other non-solvent materials, and 40% MIBK, rather than the maximum allowed 1%. The heating up of this excess MOM charge was the main cause of the runaway reaction. CSB criticized the lack of understanding of the chemistry of the process by the operators as a key shortcoming leading to the explosion.

10.8 According to CSB, the operators expressed dissatisfaction with inadequate training in the new Methomyl DCS. Although the Larvin system was supposed to be similar, there

were enough differences in the system that the operators did not feel comfortable with the new system. The documentation on the new controller also was inconsistent with the way the system was operated. In addition, all requested screens for the DCS had not been implemented. In spite of these problems, the PSSR for the DCS had been checked off as complete, and the facility manager gave verbal approval for startup (although the PSSR was not formally signed off due to problems with the Bayer Action Tracking System).

10.9 There was a lower than historical level of Supervisory staff in the unit and the technical support in the unit at startup was lean and relatively inexperienced, according to the Bayer investigation. There had been more turnover in unit staff than other units, and the shift supervisors, originally one for each shift, had been reduced to one on day shift, with operations supervision switching to a team approach on each shift. At the time of the incident the more experienced supervisor was on vacation, and neither the technical advisor nor the plant engineer on the unit had experienced a unit startup.

10.10 CSB criticized the PHA for not incorporating the Process Safety Information into the PHA. Specifically, the Methomyl process in the original SOP discussed the importance of controlling the methomyl concentration in the residue heater at least five times. Yet the team concluded high residue concentration in the flasher feed was an operational issue with no consequence. They also criticized a 1994 PHA for assuming the high temperature interlock would function as intended and prevent a high concentration methomyl reaction.

10.11 CSB criticized the PSSR. In addition to checking off as adequate the preparation of the problematic DCS, the PSSR had not picked up the equipment problems previously noted in this discussion. Also, the PSSR indicated the SOP had been completed and was up-to-date, when it was not. The control system PSSR did identify some items as incomplete, but had no due dates, to fix them.

10.12 CSB also criticized the DCS control system change for problems in human factors design. Board operators reported to CSB that the screens were difficult to navigate, and the mouse-operated system was slow to respond, degrading operator awareness and

response times. The operators had requested overview screens be added to the system to reduce the need to have multiple screens simultaneously open, however they where not installed at the 2008 startup.

10.13 There are several problems noted in the CSB report regarding emergency response related to external coordination. The 911 call center received upwards of 700 phone calls overwhelming the system. As a result, the Bayer security guard tried many times to get through to 911, but the line rang busy and 911 had trouble getting through to the Bayer guard shack. At one point, emergency responders showed up at the Bayer guard shack. However, the guard informed them that he could not give out any information. Knowledge on how to coordinate traffic control and sheltering in place was missing and decisions outside the plant were uncoordinated.

10.14 The CSB report noted a history in the previous Bayer internal PSM audits with trouble with completing PSM recommendations in a timely fashion. At the time of the accident, Bayer had introduced a new Bayer Action Tracking System (BATS), but it was still not completely integrated into the plant operations. For instance according to the CSB report, the facility leader was unable to formally sign off on the startup at the Methomyl Unit using this system. One of the outstanding action items was an update of the Methomyl operating procedures.

11 Bayer Remediation Actions in Response to CSB Key Findings

Process Hazard Analysis

11.1 CSB finding: The PHA team did not validate the assumptions in the PHA including accuracy of the SOP, conformance to the SOP, and control of process safeguards.

Bayer remediation actions:
In regards to the MIC startup, the SOP's have been written. Routine changes that happen for any number of reasons go through management of change procedures and are then incorporated into the SOP's and training. They are linked to the PHA via inclusion of critical operating parameters (both instrument and procedures), which are listed as credited safeguards in the PHA. Items listed as safeguards in general discussion, but not included in the credited safeguards list are not deliberately included in the SOP. (SOURCE: Interview with Richard Lewis and Steven Feirbaugh, plus online

review of section of MIC SOP.)

11.2 CSB finding: The residue treater layers of protection to prevent a runaway reaction were inadequate.

<u>Bayer remediation actions</u>:
Layers of protection in the residue treater do not apply to MIC and the methomyl unit does not exist anymore. With regard to the layers of protection for the MIC unit, please see discussion in paragraphs 20.1 through 20.24.

11.3 CSB finding: Previous PHA action items were not closed in a timely manner, including operator training and control of process safeguards.

<u>Bayer remediation actions</u>:
The Unit Managers (Horst Siffrin and Richard Lewis) have led the development of an extensive written integrated startup manual for the MIC startup. This manual, plus the MOC/PSSR is being checked to ensure all relevant action items are properly closed out and verified prior to startup (SOURCE: Interview with Horst Siffrin, Richard Lewis, and Mike Curry and review of startup binder).

11.4 CSB finding: The methomyl unit SOP was overly complex and not reviewed and approved prior to the methomyl unit startup.

<u>Bayer remediation actions</u>:
This finding does not apply anymore with regard to the methomyl unit since it has been decommissioned. The MIC unit SOP was reviewed on line. Although lengthy, the SOP is broken down into logical, clear steps in a checklist form, with separate critical operating procedures listed. Operators are expected to access the manual, and a formal training in the system, including formal, written tests were inspected for the startup manual. Testing was developed jointly by Richard Lewis and the Training coordinator Steven Feirbaugh. Test questions appeared relevant and detailed, and would require the operator to be intimately familiar with the operating steps, critical operating parameters, and chemistry of the process. An operator has two chances to pass the test, after which if he fails he is removed from duty, per policies established by Steve Hedrick, the site manager since 2010. (SOURCE: Interview with Steven Feirbaugh, Richard Lewis, visual inspection of online manual, and interview with Steve Hedrick).

11.5 CSB finding: The SOP did not include flasher tails methomyl concentration testing as required by the original construction process safety information package.

<u>Bayer remediation actions</u>:
Methomyl SOP not relevant to the MIC process. Unit is decommissioned and removed. With regard to current operations, significant additional emphasis has been placed on

the development of SOPs, adherence to SOPs, and training by Bayer. The SOP for the modified MIC operations has been prepared by Richard Lewis in conjunction with operators. Mr. Lewis is a degreed experienced chemical engineer, with significant Production Management experience in the MIC unit. (SOURCE: Interview with Richard Lewis).

Pre-Startup Safety Review

11.6 CSB finding: The PSSR did not include a formal process involving multiple disciplines. The PSSR did not verify the completion of modifications in the field.

Bayer remediation actions:
The controls on PSSR's have been tightened under the new management of Steve Hedrick. Failure to rigorously follow the PSSR/MOC process is an offense subject to dismissal (SOURCE: Interview with Steve Hedrick and Ralph Casto).

11.7 CSB findings: Project engineers did not verify the functionality of critical DCS control and indication circuits. Operating equipment and instruments were not installed before the restart, some of which were discovered to be missing after the startup began. Equipment checkouts as required by the pre-startup safety review were incomplete.

Bayer remediation actions:
MOC/PSSR controls and commissioning procedures are more formal and rigorous in the MIC case, being personally monitored by Horst Siffrin, one of the two unit managers. (SOURCE: Interview with Horst Siffrin, observation of commissioning manual).

11.8 CSB findings: Project engineers did not verify the functionality of critical DCS control and indication circuits. Valve lineups were incomplete or incorrect.

Bayer remediation actions:
A rigorous commissioning manual has been prepared for the MIC unit.

11.9 CSB findings: Control system training was inadequate. The operators were not formally trained on the methomyl DCS and were not familiar with some of the changed units of measure used on the DCS displays.

COMMENT:
In the methomyl unit, the control system had been changed and the operators had not received complete and formal training on the new system.

With regard to the MIC operations, the DCS is the same and control interfaces are the same. Interviews with current MIC operators during the field inspection indicated they were comfortable and familiar with the DCS system. Formal MOC/PSSR commissioning procedures should assure any changes are reviewed and training is completed.

Methomyl Unit Startup

11.10 CSB findings:

- Methomyl unit board operators were not provided with computer screen displays to effectively operate all assigned process and utility systems.
- Multiple operational problems diverted the staff's attention
- Only one of the two centrifuges was operating properly.
- The new Siemens operating system was not calibrated; consequently, the staff struggled with balancing the MIBK- hexane ratio in the crystallizers.
- Operators were pressured to start the MIBK solvent recovery system because the MIBK stockpile levels were getting low.
- Operations personnel incorrectly assumed that methomyl was not being produced in the reactor even though the flasher feed sample lab results were available, which reported excessively high methomyl content in the process downstream from the reactor.
- Operators and technical staff did not troubleshoot why the centrifuges did not contain methomyl cake.
- Several required SOP steps were not completed during the methomyl unit startup:
  - The residue treater was not pre-filled with solvent.
  - The solvent was not circulated and heated to the minimum operating temperature.
  - The 7 a.m. daily residue treater liquid sample was not collected and analyzed for methomyl concentration.
- Management did not strictly enforce the safety matrix control policies. Bypassing the safety interlocks on the residue treater flasher bottoms feed valve allowed the empty residue treater to be filled with concentrated methomyl.
- Oxime system startup problems diverted operators' attention, resulting in poor communication between methomyl board operators at shift change.
- The residue treater relief system design basis was invalidated during the methomyl unit startup:
  - The design basis assumed that the safety interlocks were active, but the interlocks were bypassed.
  - The resident treater relief system design basis relied on administrative controls such as sample collection and analysis to prevent overcharging methomyl, but these controls were either incomplete or not implemented before startup.
- A runaway methomyl decomposition reaction inside the residue treater overwhelmed the vent system and caused the vessel to violently explode.

<u>Bayer remediation actions</u>:
In general, specific failures in the methomyl startup are no longer relevant as the unit no longer exists, and do not apply to the MIC. However, in so far as these failures may

represent a systemic problem, my investigations revealed a number of changes have been implemented to eliminate these failures in the future. While the new management speaks and stands behind new and strengthened safety programs and systems, the most perceptible change is noted in the staffing and management systems. There is increased staffing and supervision, focus on training, and rigorous adherence and updating of operating procedures since the Methomyl incident, particularly under the recent management team lead by Steve Hedrick. (SOURCE: interview with Steve Hedrick and individual operators.)

MIC Day Tank Shield Structure Design

11.11 CSB findings: The blast blanket design basis did not consider an impact of a large object moving at high velocity. Had the residue treater traveled in the direction of the day tank and struck the shield structure near the top of the frame it might have resulted in an MIC release into the atmosphere (see Appendix C of CSB report).

Bayer remediation actions:
Bayer has completely redesigned the MIC operations in the site. As described earlier, the methomyl unit has been decommissioned. There is no above ground storage of MIC in the redesigned plant. The extent of MIC operations is limited to a significantly smaller area of the site and is protected by multiple layers of protection.

Emergency Planning, Response, and Communication

11.12 CSB findings: The Bayer onsite emergency response did not conform to the unified command structure contained in the National Incident Management System (NIMS) protocols. Bayer did not assign a Public Information Officer (PIO) to directly communicate with the Kanawha Putnam EOC and Metro 9-1-1.

Bayer remediation actions:
Since the August 2008 incident, a Public Information Office has been assigned to directly communicate with Kanawha County LEPC. Bayer has a Public Information Director on site. Finally, since the incident, Doug Jones has been hired as Director of Emergency Services and Security. (SOURCE – Interview with Doug Jones and C.W. Sigman).

11.13 CSB findings: Unknown to Bayer emergency personnel, the Methomyl-Larvin unit air monitor system that they relied on to determine and report airborne concentrations of possible toxic chemicals was not in service the night of the incident.

Bayer remediation actions:
The methomyl unit has been decommissioned. The MIC unit has its own multilayer

continuous monitoring system. Since the incident, an MIC unit perimeter monitoring system has been added, and existing point monitoring system has been upgraded. This includes the addition of five metrological towers and five additional monitors. The mechanical integrity program that includes inspection and monitoring has also been strengthened in terms of staffing and procedures (SOURCE: Plant visit and interviews with Unit Managers Richard Lewis and Horst Siffrin and MI staff Bhadresh Prajapati).

11.14 CSB findings: Bayer had only two distant fence-line air monitors to determine the extent of chemical contaminants traveling off site.

Bayer remediation actions:
In regards to the MIC plant, the plant has multiple rings around the unit that continually sniff the air immediately at the perimeter of the unit for MIC, Phosgene and chlorine. Since the incident, an MIC unit perimeter monitoring system has been added, and existing point monitoring system has been upgraded. This includes the addition of five metrological towers and five additional monitors. (SOURCE: interview with Richard Lewis, plant inspection, and comments on the MIC system in CSB final report).

11.15 CSB findings: Although the Bayer Incident Command Center (ICC) recommended a shelter-in-place, Bayer did not notify Metro 9-1-1.

Bayer remediation actions:
According to interviews with Doug Jones, the new Emergency Services and Security Director on site and C.W. Sigman, Bayer has installed a hotline from the Bayer site and at the guard shack with Metro 911. (SOURCE: interview with Doug Jones, C.W. Sigman and Ralph Casto).

11.16 CSB findings: Bayer discontinued hot zone decontamination activities before all emergency responders were able to clean their safety gear.

Bayer remediation actions:
Since the incident, Bayer has appointed a Director of Emergency Services and Security for the site, Doug Jones. He has increased training of the emergency responders, including initiating joint training with mutual aid departments regarding how operations are handled in industrial emergencies. (SOURCE: Interviews with Doug Jones and Ralph Casto).

12 CSB Recommendations to Bayer CropScience – Research Triangle Park, NC

2008-08-I-WV-R1: Revise the corporate PHA policies and procedures to require:

a. Validation of all PHA assumptions to ensure that risk analysis of each PHA scenario specifically examines the risk(s) of intentional bypassing or other nullifications of safeguards,

Bayer Remediation Actions: Procedures have now been put in place to ensure

validation of all PHA assumptions to ensure that risk analysis of each PHA scenario specifically examines the risk(s) of intentional bypassing or other nullifications of safeguards.

b. Addressing all phases of operation and special topics including those cited in chapter 9 of "Guidelines for Hazard Evaluation Procedures" (CCPS, 2008), and

Bayer Remediation Actions: The Bayer *PHA methodology will be revised to include reviews of the items identified in chapter 9 of "Guidelines for Hazard Evaluation Procedures" (CCPS, 2008) in each PHA. Specifically the following sections will be included:*
9.1 Hazard Evaluation of Procedure-Based Operations
9.2 Hazard Evaluation Processes Controlled by Programmable Systems
9.3 Hazard Evaluation of Chemical Reactivity Hazards
9.4 Combinations of Tools
9.5 Human Factors and Human Reliability Analysis
9.6 Facility Siting
For the MIC unit HAZOP (dated May 2010), the team has considered all procedure-specific scenarios.

c. Training all PHA facilitators on the revised policies and procedures prior to assigning the facilitator to a PHA team.

Bayer Remediation Actions: PHA Facilitators will be trained on the changes to the revised policies and procedures. Revisions will be made part of the PHA training given to the PHA team prior to the conduct of each PHA.

Ensure all PHAs are updated to conform to the revised procedures.

Bayer Remediation Actions: All OSHA 1910.119 covered process PHAs will be updated with changes made in response to this recommendation at the next scheduled revalidation, or significant change to the process, whichever occurs first.

13 CSB Recommendations to Bayer CropScience, Institute plant

2008-08-I-WV-R2: Review and revise, as necessary, all Bayer production unit standard operating procedures to ensure they address all operating modes (startup, normal operation, temporary operations, emergency shutdown, emergency operations, normal shutdown, and startup following a turnaround or emergency shutdown), are accurate, and approved .

Bayer Remediation Actions: AcuTech is performing a third-party review. The targeted completion date for all Bayer CropScience SOPs is March 31, 2011. MIC review is complete, review is being written. In summary, they have found no serious problems in

the review. However, Bayer will work with AcuTech to close any gaps.

2008-08-I-WV-R3 Ensure that all facility fire brigade members are trained in the National Incident Management System, consistent with municipal and state emergency response agencies.

<u>Bayer Remediation Actions</u>: Complete. They are trained and have refresher training scheduled later this year. (Source: Interviews with Doug Jones and C.W. Sigman).

2008-08-I-WV-R4: Evaluate the fence line air monitor program against federal, state, and local regulations, and Bayer corporate policies, and upgrade and install air monitoring devices as necessary to ensure effective monitoring of potential releases of high-hazard chemicals at the perimeter of the facility.

<u>Bayer Remediation Actions</u>: Bayer has conducted a CyberRegs® search and concluded that there are no specific regulatory requirements for fence line monitoring. Bayer likewise does not have any internal policies for fence line monitoring. However, there is continuous monitoring for MIC, phosgene, and Cl_2 at the MIC unit perimeter. Also fence line monitoring has been improved.

2008-08-I-WV-R5 Commission an independent human factors and ergonomics study of all Institute site PSM/RMP covered process control rooms to evaluate the human-control system interface, operator fatigue, and control system familiarity and training. Develop and implement a plan to resolve all recommendations identified in the study that includes assigned responsibilities, required corrective actions, and completion dates.

<u>Bayer Remediation Actions</u>: AcuTech is conducting a third party review. They started in the MIC/Phosgene area. Bayer will resolve the findings.

C. PROCESS SAFETY MANAGEMENT PROGRAM AT THE BAYER CROPSCIENCE FACILITY, INSTITUTE, WEST VIRGINIA

14 Overview

14.1 The Institute, West Virginia Bayer CropScience operations are covered by the Occupational Safety and Health Administration (OSHA) Process Safety Management regulation (29 CFR 1910.119). The objective of the regulation is to prevent or minimize the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals. The regulation requires a comprehensive management program: a holistic approach that integrates technologies, procedures, and management practices.

14.2 The process safety management regulation applies to processes which involve certain specified chemicals (see Appendix A of the regulation) at or above threshold quantities, processes which involve flammable liquids or gases on-site in one location, in quantities of 10,000 pounds or more (subject to few exceptions), and processes which involve the manufacture of explosives and pyrotechnics. Hydrocarbon fuels, which may be excluded if used solely as a fuel, are included if the fuel is part of a process covered by this regulation. In addition, the regulation does not apply to retail facilities, oil or gas well drilling or servicing operations, or normally unoccupied remote facilities.

14.3 The management system required by the OSHA process safety management regulation envisions a holistic program with checks and balances aimed at creating multiple barriers of protection. The performance-based approach does not prescribe specific methods and approaches, thus giving facilities the flexibility for customizing the methods to best meet their needs and organizational structures. The process hazard analysis (PHA) is the heart of the program and impacts or interfaces with all of the other elements. However, it must also be pointed out that all elements of the program must be implemented in their entirety to get the maximum benefit and accomplish the ultimate objective, *i.e.*, reduce the frequency and severity of chemical plant accidents.

14.4 The fourteen elements of the OSHA process safety management regulation are listed below:

- Employee Participation
- Process Hazard Analysis
- Training
- Pre-startup Safety Review
- Hot Work Permit
- Incident Investigation
- Compliance Audit
- Process Safety Information
- Operating Procedures
- Contractors
- Mechanical Integrity
- Management of Change
- Emergency Planning and Response
- Trade Secrets

14.5 Bayer CropScience has developed and implemented a PSM program that addresses each of the fourteen elements of the OSHA process safety management regulation.

15 OSHA Citations on PSM Program

15.1 Following the August 2008 incident, OSHA cited Bayer CropScience for non-compliance with the PSM standard. The citations included items regarding the process hazards analysis, operating procedures, training, management of change, and mechanical integrity under the process safety management regulation. Bayer CropScience was also cited under the personal protective equipment requirements and the respirator training requirements.

15.2 The OSHA citations amounted to a total of $143,000. A settlement agreement with certain changes was later agreed to and signed between OSHA and Bayer CropScience for a total fine of $143,000.

15.3 Since the August 2008 incident, the methomyl unit has been decommissioned. As such the specific issues related to the methomyl unit are not relevant anymore. However, insofar as programmatic issues related to the specific elements of the PSM program identified by the OSHA citations, I have made every effort to determine the current status of those elements. Each one of those elements is addressed separately in the following paragraphs.

15.4 Process Hazards Analysis:

Even though the methomyl unit has been decommissioned, the OSHA citations with

regard to the PHA element of the PSM program are relevant in the sense that they may reflect on the other PHA's. With regard to PHA's, since the August 2008 incident, the following has occurred:

- The MIC PHA has been redone. All the R&D reports since the 1960's and additional experimental work for determining reactive hazards information (*e.g.*, Fauske report, VSP data) with various potential contaminants was made available to the PHA team. During the PHA, there are two facilitators, one is an expert on the chemical process and another one is an expert on the PHA process. There is a special emphasis on ensuring the multi-disciplinary background of the team members. The rigor of the PHA is also apparent from the length of time it now takes to conduct the PHA. In addition, the PHA and the PSSR has been reviewed by third-party and recommendations have been implemented.
- PHAs include critical operating parameters (both instrument and procedures), which are listed as credited safeguards in the PHA.
- Safety integrity level calculations are also being done.
- The Unit Managers have led the development of an extensive written integrated startup manual for the MIC startup. This manual, plus the MOC/PSSR is being checked to ensure all relevant action items are properly closed out and verified prior to startup.
- With regard to facility siting, Bayer has completed a third-party project entitled, "MIC/Phosgene Design Consideration Assessment." This report addresses concerns raised by OSHA citations on facility siting. (Note: The reason this was a repeat citation following the August 2008 incident is because methomyl unit PHA had been conducted before the 2006 inspection and citation).
- With regard to follow-up on PHA action items, there is now a rigorous adherence to the BATS database and tracking.

15.5 Operating Procedures and Training:

Even though the methomyl unit has been decommissioned, the OSHA citations with regard to the operating procedures and training elements of the PSM program are relevant

in the sense that they may reflect on other procedures and training. With regard to the MIC unit, although lengthy, the SOP is broken down into logical, clear steps in a checklist form, with separate critical operating procedures listed. Operators are expected to access the manual, and a formal training in the system, including formal, written tests were inspected for the startup manual. Testing was developed jointly by Richard Lewis and the Training coordinator Steven Feirbaugh. Test questions appeared relevant and detailed, and would require the operator to be intimately familiar with the operating steps, critical operating parameters, and chemistry of the process. An operator has two opportunities to pass the test, after which if he fails, he is removed from duty, per policies established by Steve Hedrick, the site manager since 2010.

Defined operator actions and procedures are identified in the HAZOP for credit. These are followed up in the SOP. Emergency actions are now identified in the SOP's and the actions necessary by the operators.

Joe Davenport, Union Representative, was asked to solicit input from the operators regarding refresher training and these recommendations were incorporated into the program.

Currently, there is significant additional emphasis on development of SOPs, adherence to SOPs, and training by Bayer. The revised SOP has been prepared by Richard Lewis in conjunction with operators. Mr. Lewis is a degreed experienced chemical engineer, with significant Production Management experience in the MIC unit.

15.6 Management of Change

Even though the methomyl unit has been decommissioned, the OSHA citations with regard to the management of change element of the PSM program are relevant in the sense that they may reflect on changes in the plant. Currently, procedures have been changed where update and management of change compliance is signed off by management. For the MIC unit, the procedures are written and complete. Any changes

made are being reviewed to make sure they are in compliance with management of change procedures.

15.7 Mechanical Integrity

One of the OSHA citations dealt with frequency of inspections and tests of the MIC stripping still within the timeframe required by API 510. Even though the methomyl unit does not exist anymore, the citation is relevant with regard to the mechanical integrity program for the site. Since the August 2008 incident, Bayer has revamped the mechanical integrity program by adding staff (specific to mechanical integrity expertise) and developing programs for compliance with API 510 (for pressure vessels), API 570 (for piping), and API 653 (for flat bottom storage tanks). A Microsoft Access®-based database developed by Bayer Technical Services has been implemented to track inspection due dates and inspection frequency and testing methods are developed based on the industry standards. Two contractor firms, MISTRAL and TRIAD have been engaged to conduct inspection and testing.

Current plant procedures do not allow startup for any unit including the MIC unit when there is any overdue inspection item.

16 Bayer Incident Investigation and Changes to the PSM Program

As required by the PSM regulation, Bayer conducted an internal incident investigation for the August 2008 incident. Following are the recommendations from the Bayer investigation report and associated remedial steps and follow-up conducted by Bayer.

16.1 Review and improve the management of safety and operational interlock safeguards and the adherence to interlock management procedures.

Bayer remediation action:
This has been procedurally emphasized in the plant, with much better compliance due to emphasis, especially under Steve Hedrick's management. (SOURCE: Interview with Steve Hedrick and Operations leaders and managers).

16.2 Identify and apply methods to improve strict adherence to the Standard Operating Procedures (SOPs)

<u>Bayer remediation action:</u>
This has been procedurally emphasized in the plant, with much better compliance due to emphasis, especially under Steve Hedrick's management. (SOURCE: Interview with Steve Hedrick and Operations leaders and managers).

16.3 Evaluate and identify if additional methods for monitoring the Residue Treater and the Flasher tails stream for reactive chemical content are available and appropriate for this type of service.

Comment – no longer applies.

16.4 Perform a new PHA for the methomyl unit which incorporates these recommendations and other safety improvements recommended by the rebuild team.

Comment – no longer applies.

16.5 Discuss, educate, and inform all site employees regarding the essential findings and recommendations from this investigation.

<u>Bayer remediation action:</u>
The Bayer incident investigation report is available to employees. Also, some lessons learned and dissemination tolls have been developed. Bayer intends to continue with widespread dissemination of lessons learned. (SOURCE: Interview with Steve Hedrick and Operations leaders and managers).

16.6 Evaluate the adequacy of the level of technical support in the unit.

<u>Bayer remediation action:</u>
Technical support with regard to the methomyl unit is no longer applicable because the methomyl unit has been decommissioned. However, in general, with regard to all the other units for Bayer CropScience operations, technical support has increased in the units, and engineering professionals, either with extensive production experience, or with PSM subject matter expertise have been placed in charge of line operations.

16.7 Redesign of control systems graphics with operator involvement

Comment: Please note that the controls in the MIC unit are quite different as compared to the methomyl unit. Operators in the MIC unit were interviewed with regard to DCS at MIC. They said that they have appropriate input and are comfortable with the control systems and graphics. (SOURCE: field inspection and discussion with MIC operators).

16.8 Incorporate critical process steps, parameters, and procedures, etc. into the control (*e.g.*,

window to require input of sample analysis results before heating)

<u>Bayer remediation action:</u>
This recommendation with regard to the methomyl unit is no longer applicable because the methomyl unit has been decommissioned. However, with regard to the MIC unit, there is no such analogous batch process that would require manual sample input.

16.9 Improve bypass process to ensure control for interlock bypasses and multi-level management approval. Ensure adherence of the bypass procedure.

<u>Bayer remediation action:</u>
The plant has introduced a rigorous by pass control program. Only Unit managers are allowed to authorize bypasses. Software changes prevent managers from leaving in supervisory mode (locks after 30 seconds of inactivity. (SOURCE: Interview with Horst Siffrin, Richard Lewis and site inspections).

16.10 Review Control System project implementation for completeness including ensuring all alarm settings are programmed, interlocks are active, etc.

<u>Bayer remediation action:</u>
MIC unit procedures include formal commissioning procedures. Also, the MOC/PSSR procedures will verify this. (SOURCE: interview with Horst Siffrin).

16.11 Obtain status MOCR/PSSR for controls upgrade

<u>Bayer remediation action:</u>
There is an increased emphasis and enforcement of MOC/PSSR procedures and MIC Commissioning Procedures.

16.12 Provide a process simulator for control systems and initial/refresher training.

<u>Bayer remediation action:</u>
Siemens had a simulator that simulates methomyl process conditions and operator can sit there and simulate the distillation process. The recommendation refers to using the simulator more frequently particularly for refresher training. The methomyl unit and the associated Siemens control system do not exist anymore.

16.13 Review Control System project implementation for completeness including ensuring all alarm settings are programmed, interlocks are active, etc.

<u>Bayer Remediation Actions</u>:
An interlock, essentially, is an automatic "lock", designed to prevent an unsafe event from happening. The safety computer control system has the command built into the program that prevents a device from operating should an undesirable situation exist. There were two types of interlocks in the MOM unit, safety interlocks, which were critical to safety; and operations interlocks, which could be overridden by operations supervisors. Operations Supervisor's overrides were to allow start up activities or other

deviations from normal, steady state operations that were part of process operations. Unlike safety interlocks, operations interlocks could be bypassed by the operations supervisor via a password.

In the MOM residue treater, safety interlock on low temperature and high pressure was built into the control system to prevent the feed valve from opening when the temperature was below the minimum set temperature and the pressure was above the maximum pressure established by the programmed limits. Also, an operations interlock was in place that prevented the valve from opening when recirculation to the residue treater cooler was not operating.

While the specific comments and remediation does not apply to the methomyl unit any more, changes have been made in response to this recommendation. These changes include:

- *every control loop including all alarms and interlocks are being checked and signed off by teams (these checks include agreement with the safety matrix and PHA, the graphics, and messages on the graphics),*
- *all the documentation of these checkouts are being verified during the pre-startup safety review,*
- *check of the physical installation wiring,*
- *check of the I/O (input/output) and graphics,*
- *check of the safety interlocks,*
- *physically checking valve positions,*
- *database to monitor and record the whole checkout process, and*
- *calibration of instruments checked before installation.*

16.14 Improve the completeness of the safety file and involvement of knowledgeable people in PHAs

<u>Bayer remediation action:</u>
Bayer is in the process of redoing all the PHAs in a rigorous manner. The MIC unit PHA has been completed. A review of the MIC PHA vs the Methomyl PHA showed a much greater cross section of technical specialists in the MIC HAZOP (Methomyl HAZOP was limited to operating personnel and PSM specialist in attendee list). (SOURCE: review of methomyl and MIC PHA's).

16.15 Review staffing levels for adequate support of operations:

a. Operators (need to qualify more operators for more jobs and need to build and retain experience to ensure community
b. TAs (need additional engineers to support units and need to build and retain experience to ensure continuity
c. I/E's (need additional I/E's to support units)
d. Maintenance (need additional support and should be dedicated to units)

<u>Bayer remediation action:</u>
Since the August 2008 incident, two additional levels of supervision (shift team leaders and 2nd plant managers) have been added and staff added in different places. The changes include:

- *All operators are encouraged to learn all jobs.*
- *Technical advice is available from the shift team leaders (since the August 2008 incident, 4 shift team leaders in the ECC and 4 shift team leaders in the WCC have been added)*
- *Additional hires have been made for I/E's during the last 12 months.*
- *With regard to maintenance and mechanical integrity, staff with appropriate expertise has been hired. The number of maintenance supervisors has been doubled and dedicated maintenance personnel are available for the ECC and WCC.*

16.16 Continue to address overtime issues with planned hiring of new operators and cross-training

<u>Bayer remediation action:</u>
Bayer has procedures and contractual language on overtime. A third-party, AcuTech, is developing a report and guidance with regard to overtime in compliance with recent industry standard on fatigue, API-755. The AcuTech report is expected imminently and Bayer intends to address the recommendations in an appropriate manner in keeping with labor issues and other collective bargaining agreements.

16.17 Review staffing levels for adequate support of emergency response

<u>Bayer remediation action:</u>
There are currently about 80 people trained for the emergency squad. In addition, Doug Jones, the new Director of Emergency Services and Security has demonstrated compliance with the NIMS with an internal audit.

16.18 Review of the SOPS for the Units and Site Procedures for accuracy and completeness and also simplify where possible to facilitate them being followed.

<u>Comment</u>:
Reviewed SOP section and layout, and discussed with Richard Lewis. The procedures looked complete and straight forward to follow.

16.19 Eliminate undocumented shortcut methods by incorporating them into procedures if they are valid.

<u>Comment</u>:
Enforcement and updating of SOPs has been stressed since the incident, and especially under Steve Hedrick. Failure to follow written SOP's is an offense that can lead to dismissal. (SOURCE: discussion with Steve Hedrick, confirmation with Unit Managers, Operators, and Union Representative).

16.20 Enforce requirement to follow all procedures as written for all levels of employment. Verify adherence.

<u>Comment</u>:
Enforcement and updating of SOPs has been stressed since the incident, and especially under Steve Hedrick. Failure to follow written SOP's is an offense that can lead to dismissal. (SOURCE: discussion with Steve Hedrick, confirmation with Unit Managers, Operators, and Union Representative).

16.21 Incorporate Checklists, quick references, etc. into procedures for critical activities such as startups, shutdowns, etc.

<u>Comment</u>:
Review of MIC SOP showed checklists and quick references for critical procedures for regular (cold) startup section. (SOURCE: interview with Richard Lewis with simultaneous review of SOP).

16.22 Enforce adherence of the MOC/PSSR procedures

<u>Comment :</u>
Enforcement of MOCR/PSSR procedure is a plant priority. See previous comments

16.23 Ensure all identified pre-startup safety requirements are actually completed prior to starting a process or a change

<u>Comment</u>:
See previous comments on more rigorous enforcement of MOC/PSSR and comments about detailed Commissioning PSSR manual compiled by Horst Siffrin for PSSR startup.

16.24 Review site-wide implementation for IN-tools for sufficient data capture with input from I/E's (instrument/electrical technicians)

<u>Comment</u>:
This is being done currently anywhere on site where IN-tools is being used. It so happens that currently IN-tools is being used only in the LARVIN unit.

16.25 In regard to inadequate separation of solvents in the MIBK/Hexane distillation column, extra MIBK entering the system through instrument "drip" and side-draw condenser malfunctioning leaving more MIBK in the system; correct by implementing a procedural and/or controls systems safeguards to ensure that the methomyl process solvent purity is maintained above minimum standards for safe operations.

<u>Comment:</u>
This recommendation is no longer relevant as the methomyl unit has been decommissioned.

16.26 In regards to the fact that operators thought there was little or no methomyl in the back end of the process, no daily sample taken at 0700 to verify concentrations in treater, no sample taken to verify concentrations prior to initiating heating of the Treater contents, residue treater not heated and circulated prior to feeding; correct by retraining operators in the hazards of the process and emphasizing the need to follow procedures and to take samples as specified.

Comment:
This recommendation is no longer relevant as the methomyl unit has been decommissioned.

16.27 In regards to "supervisor's" profile left logged in at the control panel; correct by implementing a timer in the control systems to automatically logoff supervisor, manager and administrator profile after 2 minutes to prevent unauthorized use.

Bayer remediation action:
Software change was made and with unit decommissioned is not relevant to Methomyl. This feature is present in the MIC and Larvin control system, with a 30 second automatic logoff. (SOURCE: ECC Unit manager interview).

17 Current Status of PSM Program in the MIC Unit

17.1 PSM program requires continuous activities with regard to adherence to procedures, inspection activities, and programmatic requirements related to each of the 14 PSM program elements. As such, it is difficult to comment about a plant's PSM compliance status at any given point. However, based on my interviews, inspection of the site, and inspections of documents I have made certain conclusions that are described in the following paragraphs.

17.2 The Bayer plant management and employees are trying their best to comply with and stay in continuing compliance with the letter and intent of the PSM regulation.

17.3 Regarding the CSB findings, Bayer has developed remediation plans that have been implemented or in various stages of implementation.

17.4 Regarding the OSHA citations, Bayer has developed remediation plans that have been implemented or in various stages of implementation.

17.5 Regarding Bayer's own internal investigation and findings, Bayer has developed remediation plans that have been implemented or in various stages of implementation.

17.6 Bayer commissioned a third-party review of its PHA and PSSR for the MIC unit. Bayer has taken the recommendations provided by the third party review and implemented them or in various stages of implementation.

D. PROBABILISTIC RISK OF A CATASTROPHIC INCIDENT INVOLVING MIC AT THE BAYER FACILITY

18 Risk

18.1 For simplistic purposes, **risk** can be defined as the expected damage that a given event will cause. The damage may be monetary, human, or any other measure that can have a number put to it. Risk can also include situations in which an event causes a gain rather than damage. The calculation is done in the same way in either case -- as a function of the probability and the consequence.

18.2 The **probability** of an event (1% chance of failure in the next year, 50% chance of failure in 100 years, etc.) is the first piece of information used in the risk. Sometimes the probability is expressed as a frequency that the event will occur; for example, an event may be estimated to occur once every 10 years or once every 100 years.

18.3 The second component of risk is the **consequence** faced if the event occurs; for example, if the event has occurred, it may affect ten people in some way or cause $1,000 worth of damage to something. The consequence and probability of an event almost always has to be estimated by an expert because there are many complicated factors that may depend on each other in a complex way, and no scenario is exactly like one that has been encountered before.

18.4 These two pieces of information together can be used to obtain the expected damage of an event. Take, as an example, a situation in which an action leads to an event that occurs 10% of the time and causes $1,000 worth of damage. Since the action only causes an event 10% of the time, it wouldn't make sense to say that the risk of the action is $1,000; you would only lose $1,000 one-tenth of the time on average. Likewise, it wouldn't make sense to say that there is zero dollars worth of risk because the chance of

the event is so low; chances are, if you perform the action enough times, the event will occur at some point and you will lose $1,000.

18.5 The way that risk is formally assessed is as a product of the two pieces of information: the probability of event multiplied by the consequence that the event would have. Thus, in our simple problem, the risk would be $100, or 10% probability multiplied by $1,000 of consequence. This type of risk assessment is called **probabilistic.** The opposite of probabilistic is **deterministic**. Probabilistic risk assessments are usually better in cases like this because they take uncertainty into account, while a deterministic assessment does not.

18.6 Risk assessment is a very powerful tool in several ways. A risk assessment can be performed to see if the risk is at a low enough level to make a given action acceptable. If the risk is lower than some target, the action can be performed. If it is too high for the target, it simply shouldn't be done. Risk assessment can also be used to choose between alternatives by performing an assessment on many different alternatives and then picking the one with the least risk.

18.7 Perhaps the most important thing to understand is that risk can be decreased by lowering the probability that an action will lead to an event or by lowering the consequence of the event, but the only way to reduce risk to zero is not to perform the action at all.

18.8 In a chemical process, there are many ways to lower the consequence and probability of an event. Lowering the probability may be as simple as using a cooler so that a tank does not get too hot or as complicated as using an intricate control system to make sure that a chemical enters the tank at the proper temperature, which, in turn, keeps the tank at a safe temperature. Likewise, the consequence of an event can be lowered by simple or complicated means. These means usually build upon each other in a way that creates layers of protection that lower risk. These layers of protection are often created so that if one or a few fail, there are still several layers left to lower the chance of an event occurring. In general, the more layers that are added, the less risk there will be; however

there may be monetary reasons why a company would not add all of the layers they could.

18.9 When these layers of protection lower probability, they do so in a way that can be easily calculated under the assumption that they are independent. Consider the example from earlier, where an action causes an event 10% of the time. Now add an extra measure of prevention so that if an action causes the event, the event only causes a consequence 10% of the time. In this case, an action only causes the consequence ten percent of ten percent of the time, or one percent of the time. The consequence is still $1,000, but since the probability has been lowered, the risk is only $10. The same result would have come from somehow lowering the consequence to $100 while keeping the probability the same. Figure 4 is an illustration of this concept.

Figure 4: An Illustration of the Calculation of Probability
(Note: This can be generalized to any problem that has a probability attached to it)

18.10 The main idea of risk assessment is that two things need to be quantified: probability and consequence. These numbers are not usually easy to calculate and require experience and good information to be estimated accurately. The quantities can be modified by adding or foregoing layers of protection. The risk in a probabilistic assessment is not strictly the consequence that would occur if the event were to occur; it is weighted by the probability of occurrence. The risk can be used to figure out if a given configuration is acceptable or to compare to other configurations to find the optimum solution.

18.11 A probabilistic risk assessment on the Bayer CropScience MIC unit is the method used in this report. Further details will be provided in a later section.

19 MIC Release Scenarios

19.1 One of the main catastrophic scenarios of interest for release of MIC would be the accidental or intentional addition of water to a store of MIC or a part of the process that contains MIC. This is because water reacts with MIC to create carbon dioxide, other products of decomposition and heat. Carbon dioxide cannot be condensed to liquid at the operating temperatures and pressures. If enough carbon dioxide gas builds up, along with the loss of strength in the tank from the added heat, it can break a storage tank and cause a release of the MIC that is left.

19.2 Before the reconfiguration of the MIC unit, it would have been possible that outside factors could cause a failure of a storage tank and release of MIC. This is now highly improbable since the storage tanks have been moved underground and the space that the MIC piping takes up has been greatly reduced. In the same way, it is improbable that a new tank would get a crack or a leak in it in a short operating time without some outside factor acting on it.

19.3 The main question of the scenario where water is added into a part of the process where MIC is present in large quantities is how the water could be introduced. The addition of water to the process is not as simple as it might seem; many measures have been taken to ensure that water is not used where it does not need to be used for this very reason. One of these measures is the use of alternative heating and cooling fluids in the process that will not cause an uncontrolled reaction if or when they are mixed with MIC. These include chloroform and phosgene, of which phosgene is already used in the process.

19.4 There also are many possible redundant safeguards designed to make sure that large quantities of water don’t find their way into MIC. These may be as simple as an alarm when water concentration in a stream gets too high or keeping water pressure low so that it cannot flow into the process, or as complicated as an automated control system that closes valves or diverts flow when certain events occur. The fact that these safeguards may not work is the reason we use a probabilistic risk assessment instead of a

deterministic risk assessment.

19.5 The other consideration that, unfortunately, has to be made is the introduction of water to the MIC process in a 'sabotage' scenario, where one person or a group of people with knowledge of the process are able to find a way to introduce water into a store of MIC. This sabotage scenario is highly unlikely due to the many protective measures (*e.g.*, employee background checks, video surveillance, security guards, limited access) that the plant has, but it still has to be considered.

19.6 The most likely way for a saboteur to be able to put water into the system is through one of 16 accessible valves between the MIC refining still and the MIC storage tank (see Figure 5). It is possible to connect a source of water (like a water hose) to any of these valves and introduce water to the process, which would then flow to the MIC holding tank. Of course, this is much easier said than done for the reasons stated above, as well as the fact that there is no readily available source of water that could be connected to a valve around that part of the process. However, even though the chance is small, it must be looked at because a sabotage scenario would bypass some of the safety measures in place in the MIC unit, and it is always a concern of the public that something like this could happen.

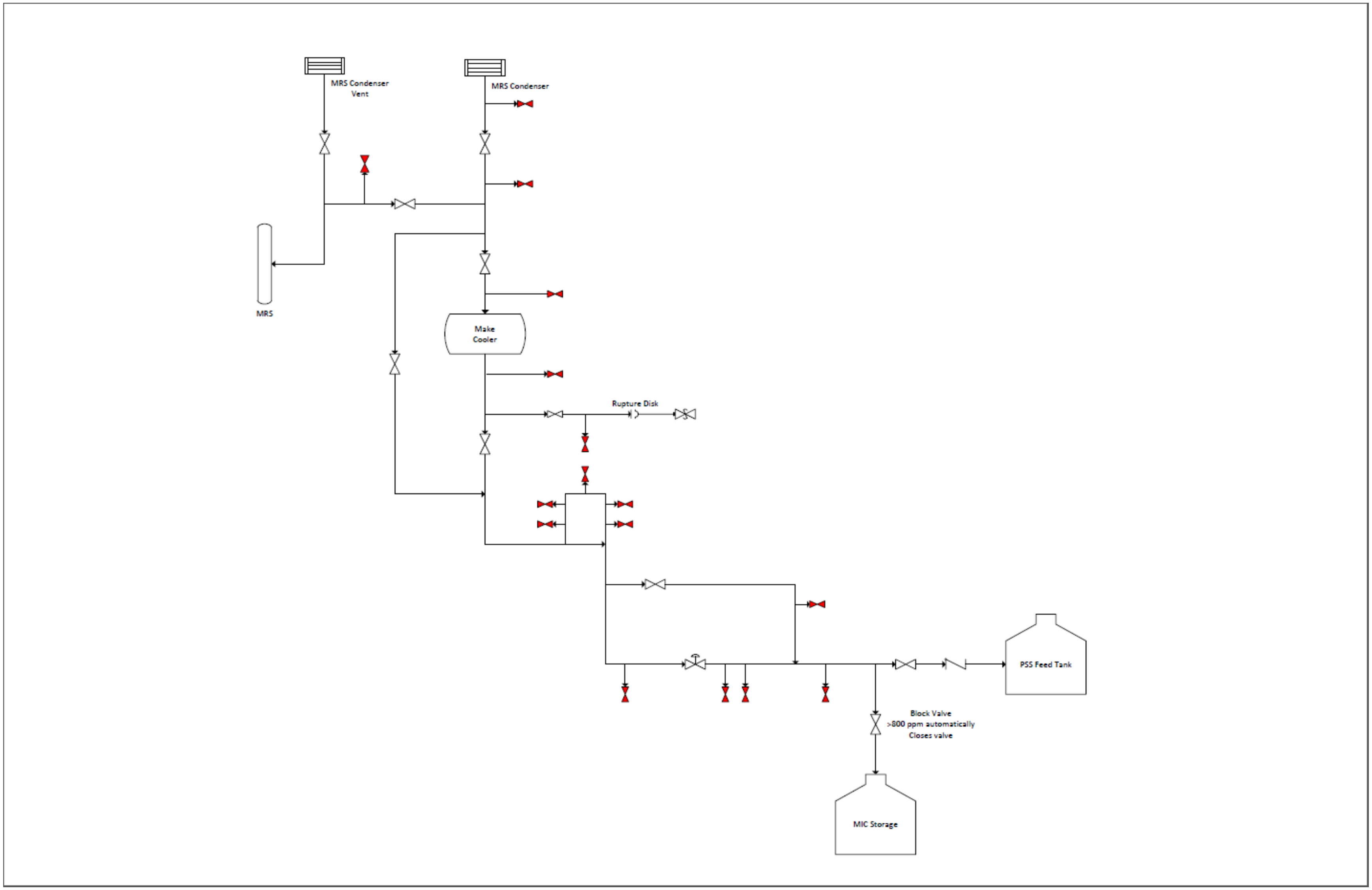

Figure 5: Valve Diagram (Valves highlighted in red are potential introduction points for water into the process)

20 Mitigation Systems and Layers of Protection

20.1 The Bayer MIC unit is protected by a series of layers of protection designed to prevent releases, and should they occur, safely control and contain any releases to protect the public and employees.

20.2 At the most inner layer, there is a series of engineering controls designed into the process to detect, shutdown the process, and contain any events before they could pose a significant risk to employees or public.

20.3 Chloroform, a non-flammable liquid, is used as solvent throughout system as it does not react with MIC. Chilled chloroform is used to chill solvent-chloroform coolers, reactor vent condenser, and the MIC refining still make cooler. The chilled chloroform is cooled using brine cooling. Water and brine are separated from MIC contact with the chloroform intermediate cooling system. Water is used in a few places for cooling. However, the locations where water is used, the pressure of the water is kept below the process fluid pressures. Therefore, in the event of a leak, MIC leaks into the water, rather than water leaking into the MIC. In regards to MIC leak into water, the reaction is much slower and less of a hazard, and can be detected via CO_2 sensors and the situation corrected.

20.4 Within the heat exchangers, the metal contacting the process chemicals are highly corrosion resistant, nickel-chrome alloys Inconel 600 and Monel.

20.5 Within the MIC refining still, a near-infrared spectrophotometer has been installed to measure any potential water contamination at ppm-levels in the MIC refining still make stream.

20.6 CO_2 analyzers measure the amount of CO_2 in two different vent streams throughout the process. The process is continuously monitored at these points using a near-infrared analyzer that can detect CO_2 at ppm levels. CO_2 is a product of the reaction of MIC, Phosgene, and Methyl Carbamyl Chloride (MCC), all chemicals involved in the MIC production. The system can detect both gradual buildup of CO_2 over several days (very small leak), and larger leaks. So in the unlikely event that there is a leak

of water into the MIC, it is quickly detected and rectified. It is normal to have small amounts of water in the process, as it is present in the recycled chloroform, monomethyl amine, (MMA) and fresh chloroform makeup. Thus, the system monitors for accumulations above the normal levels.

20.7 Steam is used to vaporize MMA and Phosgene. The steam used to vaporize the MMA is at a pressure 10 psig lower than the MMA. The steam used to vaporize the phosgene is 7 psig lower than the phosgene pressure. Thus, leaks in the vaporizer tend to result in phosgene and MMA leaking into the steam, and not the other way around. There are some places where steam pressure is higher than process pressure, but the reliability is increased by the use of the sophisticated tantalum exchangers and other detection techniques.

20.8 The process piping from the MIC storage to the aldicarb and carbaryl units use double-walled piping. In a double-walled piping system, an outer pipe acts as a second barrier to any leaks that might develop within the inner pipe, which carries the process fluid. In addition, the annulus between the inner and outer piping is continuously "sniffed" by a continuous gas sampling system for phosgene and MIC leaks, so any potential leaks can be quickly detected and rectified.

20.9 All vents and pressure relief devices are directed to an emergency vent scrubber and flare system. The system has an estimated capacity of 150,000 pounds per hour of MIC it can destroy and safely dispose of. It can handle up to 60,000 pounds per hour of liquid MIC. The flare it is attached to can handle up to 200,000 pounds per hour of MIC with assist from methane gas built into the system. (Note: Total storage for the modified MIC operations is a maximum 50,000 pounds).

20.10 The pure MIC product is kept chilled at about -5^{o}C to reduce the vapor pressure and slow down and manage any reaction in the unlikely possibility of water contamination in the MIC. Coolers to the tank maintain this temperature. Should the process become contaminated, the MIC storage tanks are protected by remote, automatically closing block valves that close when water content greater than 800 ppm is detected. The tanks are underground, below a 5-psi blast-resistant building designed to protect the tanks and process piping above the tanks. The atmosphere in

the building is continuously and automatically sampled and monitored for MIC to detect any leaks. The building has a controlled ventilation system, which isolates the building from the outside in the event of a leak. A water deluge system is installed within the building to manage any potential fires, and also surrounds the reinforced concrete building to further protect it. The building's electrical systems (along with the rest of the process) are electrically classified to reduce the likelihood of ignition sources. The building also has a water-mist system designed to react and destroy any potential MIC leaks. In the unlikely event of a leak of MIC into the building, the atmosphere within the building can be safely cleaned up by drawing it into carbon absorbers located in an adjacent building.

20.11 In order to safely manage the process in the event of a leak, breathing supply air is located in the control room so the operators can safely manage the process during and emergency. In the event the main breathing air is not available, back up supply air is located in Scott Air Packs located in the control room.

20.12 Those areas in the process that contain potentially flammable inventory have water deluge in process vessels to minimize the potential for escalation of the consequences, in case of any fire, by cooling and protecting the vessel.

20.13 In terms of facility siting, the MIC-containing sections of the plant have been reduced by the elimination of West Center MIC storage, and the pipe running from the MIC unit to the west side of the plant. Inventory of MIC on site was reduced by about 80% by this elimination and other changes. Now, the MIC handling processes, MIC production, Aldicarb, and Carbaryl are located next to each other, separated by roads for access and spacing in the event of an incident, while minimizing the need to transfer MIC over long distances.

20.14 Besides the special engineering features in the unit, Process Safety Management Systems help to minimize the potential for an accidental release. Changes to the system since the unfortunate incident have improved the PSM system in the unit. For instance, at startup each shift is directly supervised by a senior production engineer (startup manager). Each shift also has assigned reliability and instrument engineers, an assigned operations subject matter expert to lead the operators. A thorough

commissioning procedure has been developed, and the commissioning PSSR is being directly supervised by one of the startup managers. The development of the Standard Operating Procedures and corresponding training material and tests is being developed and written by another startup manager in conjunction with the unit operators. A Bayer CropScience plant-wide heightened focus on strict compliance with PSM requirements is also reflected in the operation of the MIC unit.

20.15 In general, Process Safety Management at Bayer is managed by four groups of practices. On a corporate level Bayer AG has issued a Process and Plant Safety Directive. The corporation, Bayer CropScience has issued Quality Health, Safety and Environment (QHSE) Policy, QHSE Key Requirements, a road map towards corporate QHSE Goals, and Implementation Directives and Guidelines. There are four certification levels that are required under the Bayer CropScience Directive. Certificate A1, Preliminary Safety, is developed at the beginning of a project. Certificate A2, Safety Design Review is next required Compliance and Practice to be meet certificate requirements are given by an A2-Design Review Guideline. Certificate A3, Detailed Design Review, is issued Once the detailed design has been satisfactorily been completed. Practice to meet the requirements is given by A3 Guideline on Process and Plant Safety Risk Assessment. Certificate A4 is given when the Pre-Startup Safety Review is ready. The A4-Pre-Startup Guideline gives compliance with this certificate's requirements.

20.16 Bayer CropScience Regional QHSE issues compliance details for Bayer that align it with U.S. regulations and Industry Codes and Standards. For instance, details on how to perform a PHA consistent with OSHA requirements are issued by Regional QHSE.

20.17 The control system for MIC is a modern Digital Control System. It includes operational alarms and operating responses that are programmed into the system to help the operator manage a potential upset or operational problem that could lead to a risk.

20.18 Within the DCS, alarms for operating conditions that begin to extend into the unsafe region are tied into clear response instructions via SOP's.

20.19 Should control at the DCS level fail to manage the problems, a second safety control system (Triconex) certified to a required reliability, monitors safety critical parameters in the process. In the event those parameters are exceeded, the Triconex system overrides the Digital Control System to shut down the plant.

20.20 Backing up high-pressure control shutdowns are pressure relief devices (pressure safety valves). These self-contained relief valves open when pressure limits are exceeded in the event the control system does not control the process, and relieve pressure safely. Each valve is custom-designed to meet pressure challenges that have been identified in team reviews, and checked against hazards identified in the PHA for consistency.

20.21 The MIC unit also has redundant automatic disposal systems, described in the engineering control systems already described. These include the normal process scrubber, an additional emergency scrubber and liquids knockout system connected to a flare, water spray, and a blast resistant (5 psi) containment building (MIC manifold building) above the underground MIC storage that is designed to contain any release in the manifold building. An ammonia vapor steam curtain, designed to react and destroy leaks of MIC, surrounds the perimeter of the unit and the MIC manifold building.

20.22 The process is monitored continuously by multi-level, detection that surrounds the process at multiple levels and continuously samples the atmosphere, alarming the unit in the event of a release and triggering a response. There is also area monitoring via closed circuit cameras that can be aimed to monitor the process and the containment building from the main control room. In the event of a leak, activation of the ammonia-steam curtain can react and destroy the leaking material.

20.23 In the event all of the preceding levels of protection fail, there is an on-site, coordinated and trained emergency response team. Included in its equipment is a new state-of-the-art large capacity foam application truck that can be used to reduce spill release rates by laying a sealing foam blanket on top of any liquid spill. Bayer has invested in a SAFER System continuous emergency warning modeling system that can do real-time modeling of incidents as they happen to aid in emergency

response decisions. There is also an automatic telephone ring-down system available for notifying individuals in the public as to what to do in the event of an emergency.

20.24 Finally, in the event the on-site response needs additional help, first responders from outside sources, coordinated through the Kanawha Putnam Emergency Planning Committee and Metro response are available to assist. Bayer has purchased a SAFER system for Metro's use. Bayer can communicate with these responding organizations from one of three separate locations via dedicated hardwired phone hotlines. Bayer and local off-site responders train jointly in emergency response activities that might be needed at the site. Bayer personnel also regularly meet, review and coordinate the emergency plans with the outside agencies. Since the August 2008 incident, the outside agencies have added a TV ticker emergency alert system, multiple upgrades on dial-in phone lines, weekly tested community alert sirens and emergency alert capability through weather radios are now able to be used for emergency alert.

Bayer has increased the coordination efforts with the Kanahwa Putnam Emergency Planning Committee. They are regularly involved in discussions and activities with the site regarding emergency response procedures. Bayer has established a hotline to improve physical communication with the emergency responders. They have developed a joint plan with the commission to clearly define roles in command hierarchy in Emergency Response Activities.

21 Probabilistic Risk Assessment

21.1 The logic behind the choice of a probabilistic risk assessment is outlined in prior sections, but it will be built upon here. A probabilistic risk assessment has the advantage of **not** making the assumption that an event has already happened; instead, it looks at the probability that something could happen and uses that probability to weigh the consequences. If we were to assume that a release of MIC had already occurred at Bayer CropScience, it would be the same as ignoring the protective measures that the plant has invested in. Likewise, to say that the measures of protection are enough to ensure that nothing will ever happen is to ignore the chance that some or all of the safety measures will fail. Neither of these situations is acceptable.

21.2 In this risk assessment, a situation in which a tube in the MIC refining still's (MRS) condenser springs a 5 mm leak and allows water to end up in the MIC storage tank will be examined. This scenario can also be adapted to a sabotage scenario, in which someone has purposely allowed water to enter the process somewhere between the MRS and the MIC storage tank. The first part of this analysis is to determine what the probability is that an event like this could occur. This will require some assumptions, analysis of the safeguards that are in place, and the method that was developed in the risk section of this report.

21.3 Water, as mentioned before, causes carbon dioxide and heat to be formed when it reacts with MIC, phosgene, and methylcarbomoylchloride (MCC). This can cause a tank to break and release its contents. The second part of this analysis is to find the consequence of such an event. This is done using what is called 'dispersion modeling' which is a computer program that, given a set of information about the chemical, the amount released, the weather conditions, and many other factors, can estimate how far a cloud of a vapor will travel. The program allows the user to define a concentration that they want to investigate, in this case the 'Immediately Dangerous to Life and Health' (IDLH) limit and the 'Emergency Response Planning Guideline Level 2' (ERPG-2) limit.

21.4 This situation is believed to be a credible scenario for the worst-case. It involves a large amount of water being fed to the main store of MIC for the site. This is not to say that there are not other possible causes of an MIC release. This was chosen as representative of a likely catastrophic scenario that could occur.

21.5 The main point of this risk assessment is to make an estimate of the effectiveness of the safety system that has been implemented for the MIC unit. This is particularly appropriate when projected consequence is high.

Probability of Release

21.6 To understand the probability of release in this case, we have to understand a little bit about the process and the safeguards in place on the process. The MRS condenser is

the last step between the MIC process and the largest single store of MIC in the plant, the underground MIC storage tank. The products that are condensed go directly to the storage tank. That is what makes this such a potentially dangerous scenario. That is why there are multiple levels of safeguards on this part of the process. These safeguards range from alarms when water concentrations are too high to a flare to burn away any released gases in the case of a release. These safeguards are summarized below:

- *Low pressure cooling water supply system:* Water is supplied at a lower pressure than the process pressure. This means that instead of water getting into MIC and going to the MIC storage tank, MIC would get into water in small amounts if the system functions properly. The system is backed up by a control system that keeps the water at a pressure lower than the process pressure and two alarms that activate when the water pressure gets close to the process pressure.

- *Water Detection in the MIC Make and Circulation Lines:* Water detection systems are used to find if there is above an acceptable concentration of water in the process. Alarms sound at 100 parts per million (ppm) and 250 ppm. At these points, an operator can take corrective action to stop the flow of water. An emergency shutdown is in place for when the water concentration hits 800 ppm, which closes a valve and blocks the line to the MIC storage tank.

- *Cooling System:* The cooling system is able to handle the heat that would be generated from the reactions caused by a 10% concentration of water in the MIC tank.

- *Temperature Sensors:* Temperature sensors are used to alert operators of high temperatures in the MIC unit. Operators must perform the correct action if they notice the alarm, which is to initiate destruction of the MIC through the emergency vent scrubber (EVS).

- *Emergency Vent Scrubber:* The emergency vent scrubber destroys MIC in the case that it has to be released. The products are then burned by the flare.

- *Flare:* The flare burns any products that are released through the emergency vent scrubber.

21.7 The first part of the risk assessment is to find out how often the first, or initiating, event will occur. This is usually based on prior experience or on published failure rate data, such as that given by the Center for Chemical Process Safety (CCPS) in their books[1]. For this scenario, the frequency of a tube springing a 5 mm leak is assumed to be 1.7×10^{-3} yr^{-1}. In other words, every year, you could expect this to

[1] CCPS, *Guidelines for Process Equipment Reliability Data*, American Institute of Chemical Engineers, 1989

happen an average of 0.0017 times.

21.8 The sabotage scenario is given a frequency of $1.0\text{x}10^{-7}$ yr^{-1}. It would be extraordinarily difficult to make this scenario work, so it was put on the same level as an unlikely chance occurrence. This scenario skips a few of the protective layers, which was taken into account in the calculations.

21.9 Now that we have the frequency of our initiating event, we can start adding the protective layers to the calculation. The calculations are not shown here, but an idea of the probability of a safety measure working will be discussed briefly, in order of their occurrence in the process:

- *Low-Pressure Cooling Supply* – For this part of the process to fail initially, a valve would first have to be improperly changed to unbalance the pressures. This is possible, but unlikely. If this was the case, however, a pressure alarm would be set off and the operator would have to respond quickly and accurately to fix the pressure difference. For safety purposes, the proper operation of the alarm and the operator's response were assumed to be quite low – about a one-in-ten chance that it would work. A one-in-ten failure rate is a widely-accepted value for the accuracy and sufficiency of human reactions in stressful and unfamiliar situations.

- *Water Detection Systems* – The sabotage scenario starts here. The first water detection system would automatically shut a valve to stop flow to the storage tank if the water concentration is too high. This was given about a one-in-ten chance to fail. If this fails, there is an alarm that alerts the operator to the presence of water in the MIC stream. The operator then has to make the correct decision on how to react to keep the water from entering the MIC tank. Once again, for safety reasons, this is given a low probability of working.

- *Redundant Cooling* – If the water has made it this far, the cooling system is designed to be able to relieve the heat from the reaction for up to 10% water. The redundant cooling system has a very low chance of failure. Also, the water will form a layer on top of the MIC, and if the refrigeration fails completely, the reaction will start, relatively at a very slow rate in the beginning.

- *Temperature Sensors* – This is the point at which the MIC would have to be destroyed if it got this far. The temperature sensors alert an operator to the increasing temperature in the tank, and it is up to the operator to make the right decisions, which would be to destroy the MIC through the EVS.

- *Emergency Vent Scrubber and Flare* – At this point, containment of MIC will be lost, but there are measures taken to make sure that it is destroyed before it reaches the atmosphere. The second-to-last line of defense in the case of an MIC release is the EVS. If it is operational, it will get rid of the MIC before

it is released to the atmosphere, in conjunction with the flare, which will burn whatever is left over. If the EVS is not working and the flare is not operational, the MIC release will be unmitigated and maximum consequence will occur. The chance that the EVS would not be operational is very low, and the chance that the flare would not work is also very low.

The exact probabilities used were taken from various process reliability sources including Lees' and CCPS guidelines.

21.10 Below are summarized the results of this risk analysis:

Table 1: Expected frequency of MIC release scenarios

Scenario	Expected Frequency
Condenser tube leak	$5.44\text{x}10^{-15}\ yr^{-1}$
Sabotage scenario	$1.60\text{x}10^{-15}\ yr^{-1}$

21.11 There are some pieces of this risk assessment that would not hold true if the concentration of water in the MIC was very high (above 10%), or about 5,000 pounds of water in the MIC storage tank. The first, as mentioned before, is that the cooling system would not be able to handle the extra heat. The second is that the temperature alarm may not give the operator time to respond properly if the water got into the tank.

Consequence of Release

21.12 This is a case where the consequence is quite severe but since the probability is very low, consequently the risk is also very low. Because of the way risk is defined, as the product of consequence and probability, a very small probability can offset a large consequence and vice-versa. However, dispersion modeling was used to find how far a plume of MIC would travel under certain conditions.

21.13 The modeling was done using a software called PHAST, which, as described before, uses the chemistry and physics of the release along with the weather conditions and other considerations to model a release of a chemical. It was found that under worst-case conditions (defined in such a way to maximize the distance that the cloud would affect) the cloud would travel far enough to be immediately dangerous to life and health (IDLH limit) about three quarters of a mile away.

21.14 The ERPG limit of concentration gives a larger area because the concentration is lower than the IDLH limit. This concentration of MIC would carry about 2.3 miles and reach the ground between 1,800 and 10,000 feet downwind.

21.15 It can be concluded from the results of this risk assessment that the probabilistic risk of the MIC process is very low. The risk itself could be calculated by multiplying the amount of people in a given affected area, say in the worst case within 2.3 miles of the point of release, and multiplying it by the probability of the release.

E. RECOMMENDATIONS FOR IMPROVEMENTS

22 Safety System Improvements

22.1 Confirmation of items mentioned in 11.7 and 11.8 should be included as part of the pre-startup procedures. Bayer should inspect these procedures mentioned and ensure that any such items are included and will be signed off on the PSSR process.

22.2 In regards to the specific recommendations related to the MIC unit startup, observations of the current PHA indicated that calculations for PSV's being taken credit for (a critical safety device credited in a PHA assumption) were dated from 2010, after the initial HAZOP performed in 2009. Prior to startup, Bayer should ensure that the design bases of all relief valves that were given credit during the PHA's are available and correct.

22.3 In Bayer's view point, failure to address the startup/shutdown hazards was not primarily due to an identification in the PHA, but failure to update and rigorously follow SOP's, and failure to rigorously enforce PSSR and bypass procedures. These are being addressed separately in the Bayer system. Nevertheless, the method used in the Methomyl HAZOP addressed startup/shutdown problems as a single guide-word in a HAZOP node. Following a step-by-step review of the specific procedure can reveal and highlight more specific procedure-dependent problems particularly for batch processes. Therefore, Bayer should review the MIC unit HAZOP (dated May 2010), and ensure that procedure-specific scenarios have been analyzed.

22.4 MIC control room operators expressed satisfaction with the control room instrumentation layout and graphics. However, Bayer should establish a review schedule for process control rooms at Institute, and have a qualified human factors specialist perform these reviews based on a timely schedule.

22.5 Since the procedure and authority for bypass of interlocks played such a significant role in the August 2008 incident, I recommend consideration of significant strengthening of systems to ensure that interlocks are not bypassed without proper procedure and authority. Recommendations for consideration include, a) addition of

electronic password system in addition to the use of keys, and b) secure the keys to the supervisor's belt with the use of a lanyard or other appropriate mechanism.

22.6 Since introduction of water to the MIC storage represents a severe consequence, consider the installation of valve locks on all entry points to the MIC lines (see Figure 5).

22.7 Formalize the communication and importance of PHA-identified critical items (*e.g.*, equipment, procedures, interlocks) through specific sessions with the operators. These sessions are normally used to communicate the findings of the PHA.

22.8 Use case histories for training and develop a more formalized system for sharing lessons learned.

22.9 Managers including the site leader need to play a visible and operational role all the time, but particularly more so during startups and shutdowns.

22.10 Operators should take a more active role in the annual review and certification of procedures. In addition, when new procedures are written, experienced operators should play the role of subject matter experts.

22.11 Consider increasing the number of people trained for the emergency response squad. Also consider additional training for the emergency response squad including training that includes interaction with the community emergency response personnel.

22.12 Bayer should ensure that all recommendations resulting from the third-party review referred to in paragraph (13) are resolved.

22.13 Ensure that SIL calculations referred to in paragraph 15.4 are completed and recommendations resolved.

22.14 Bayer should ensure that the recommendations resulting from the report referred to in paragraph 16.16 are resolved in an appropriate manner in keeping with labor issues and other collective bargaining agreements.

22.15 Bayer should ensure through the use of barricades, pylons, or other appropriate measures that the MIC unit and all MIC access points are NOT accessible to vehicles unless those vehicles are permitted through authorized work permits.

23 Management and Management Systems Improvements

23.1 Consider reorganization of the management; currently there are too many direct reports to the site manager.

23.2 Consider making changes in the training program to refocus the training. Bayer currently has an intensive training program but there are some operators who feel like the training for “what their day-to-day job” entails needs to be refocused and beefed up.

23.3 With regard to discussions in paragraph 16.15, it is recommended that BayerCropscience continue to pursue the goal of having all operators learn all jobs.

23.4 Managers need to spend more time in the plant.

F. MY OBLIGATIONS AS AN EXPERT

I, Dr. M. Sam Mannan, PE, CSP, declare that:

24 I understand that my duty in providing written reports and giving evidence is to help the Court. I confirm that I have complied and will continue to comply with my duty.

25 I confirm that insofar as the facts stated in my report are within my own knowledge I have made clear which they are and I believe them to be true, and that the opinions I have expressed represent my true and complete professional opinion.

26 I have endeavored to include in my report those matters, of which I have knowledge or of which I have been made aware, that might adversely affect the validity of my opinion. I have clearly stated any qualifications to my opinion.

27 I have shown the sources of all information I have used.

28 I will notify the court and counsels of record immediately and confirm in writing if for any reason my existing report requires any correction or qualification.

29 I understand that:

(1) My report, subject to any corrections before swearing as to its correctness, will form the evidence to be given under oath or affirmation;

(2) I may be cross-examined on my report;

____________________________________ March 14, 2011

Dr. M. Sam Mannan, PE, CSP Date